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Quantification of the Effects of Using Slats on the Inner Part of a 10MW Rotor

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Abstract

The present work attempts at quantifying the effects of using slats on the thick airfoils [4-7] of inner part of a modern multi-MW rotor [1] as a post-fix to increase power production.

In the process of doing this, the main behavior of the underlying physics is illuminated using a **simplified BEM approach**, and the effect of the lift and drag forces on local and integral power production and thrust is shown in a clear way.

Two different methods (a BEM based and a free wake lifting line method) for determining **design angles of attack and lift coefficients** corresponding to a specific loading on the inner part of the rotor are shown, and the results are compared.

For the design of the slats, a **2D CFD based optimization approach** is shown, and the final results from the algorithm for four specific inner airfoil sections on the multi-MW rotor is shown.

Finally, the impact of the alteration of the airfoil section force characteristics are shown in the design point using both a BEM based and a free wake lifting line method, and BEM based results are used to asses the effects of the addition of the slats on the **annual energy production**.

Simplified BEM approach

A simplified version of the BEM equations is derived in the paper for use in the early stages of the design of the loading on the inner part of the rotor. By specifying the axial induction, tip speed ratio and chordlength along the rotor, the required lift coefficient can be obtained without iteration. Furthermore, the separate effect of lift and drag on power production are shown clearly, illuminating the driving mechanisms and drag penalty for power production along the rotor

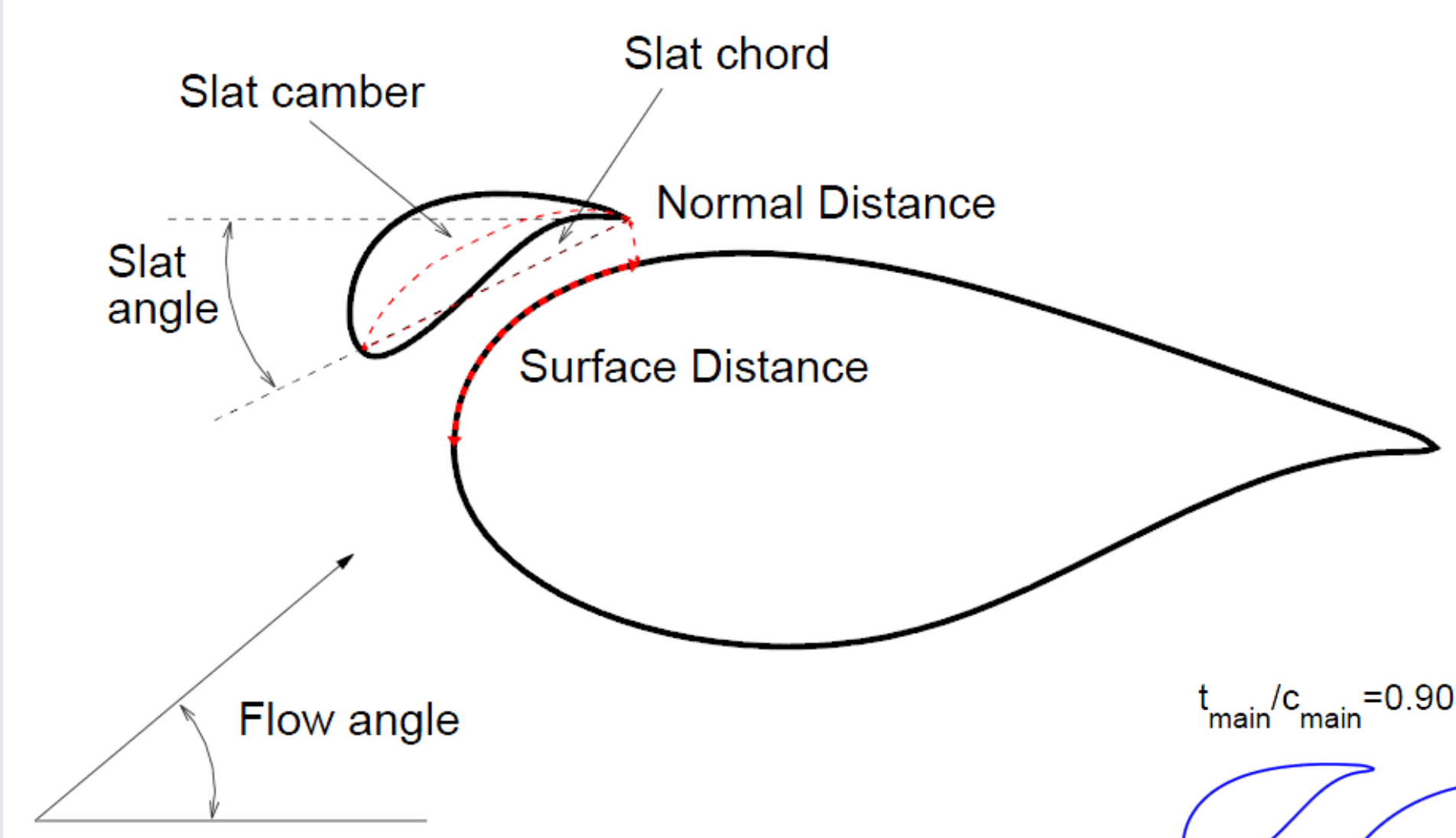
$$C_P \simeq C_{P,inviscid} + C_{P,drag}$$
$$C_{P,invisc} = \int_0^1 2C_{t,loc} \frac{1-a}{1+a'} \tilde{r} d\tilde{r}$$
$$C_{P,drag} = - \int_0^1 2C_{t,loc} \left(\frac{\lambda \tilde{r}^2}{C_d} \right) d\tilde{r}$$

Design angles and lift coefficients

In the paper, design angles and design lift coefficients obtained with the simplified BEM model and a lifting line method [2,3] is compared. It is found that even though the values of the predicted power production differ somewhat between the methods, the design points with respect to angle of attack and lift coefficient are in qualitative agreement. Since the uncertainties due to stall delay effects on the inner part of the rotor are likely to be very high, it is concluded that the design point supplied by the simplified method is of good enough accuracy to be used for initial design studies for additions of slats to the inner part of wind turbine rotors.

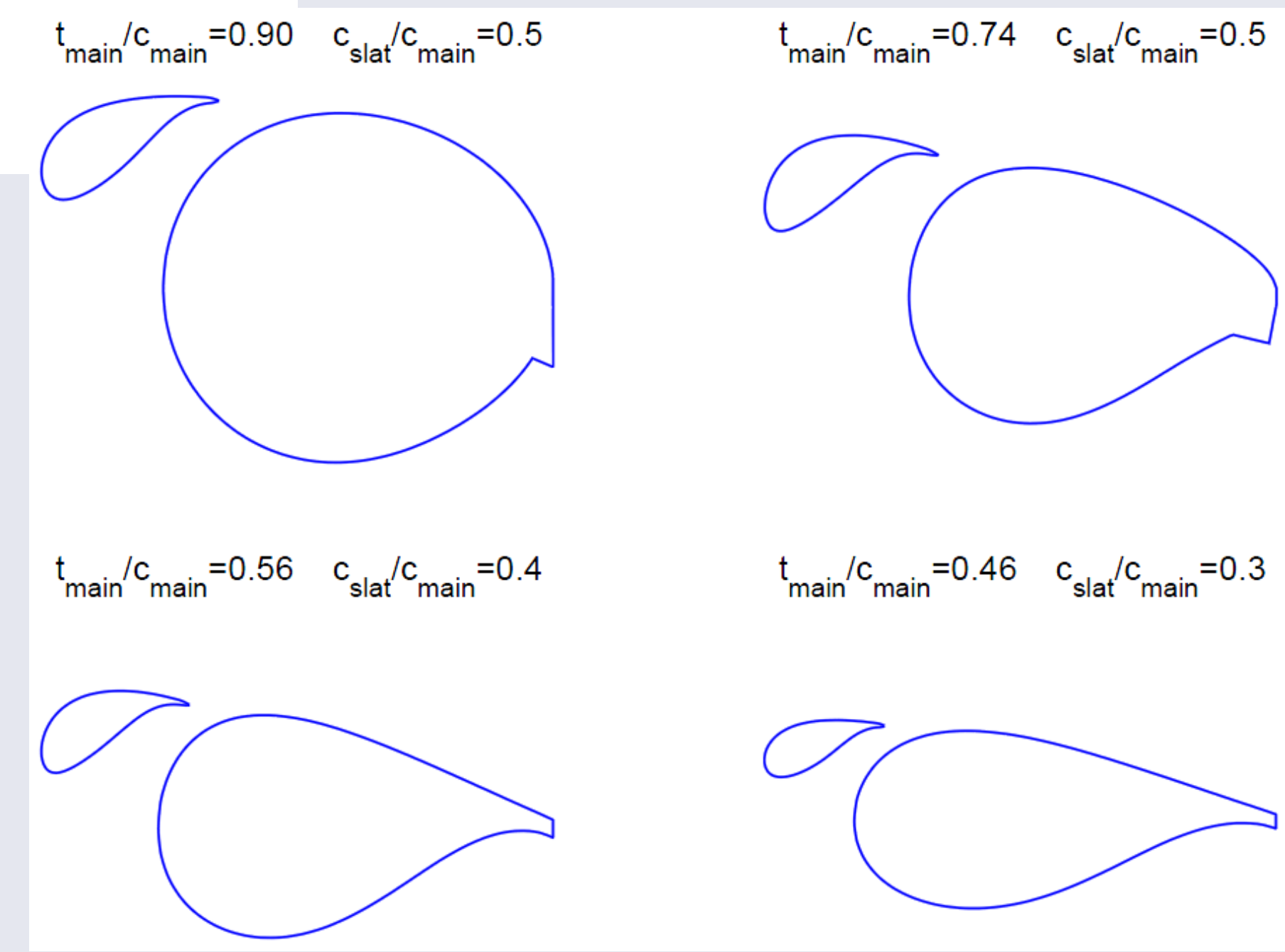
2D CFD based optimization tool

In order to be able to design the slats for the rotor, a 2D CFD based optimization tool was used. In the current work, the slat profile is obtained by adding extra camber to an existing airfoil. The location of the slat airfoil relative to the main airfoil is given by three parameters: a surface distance from the leading edge, a normal distance, and a slat angle, as shown below.

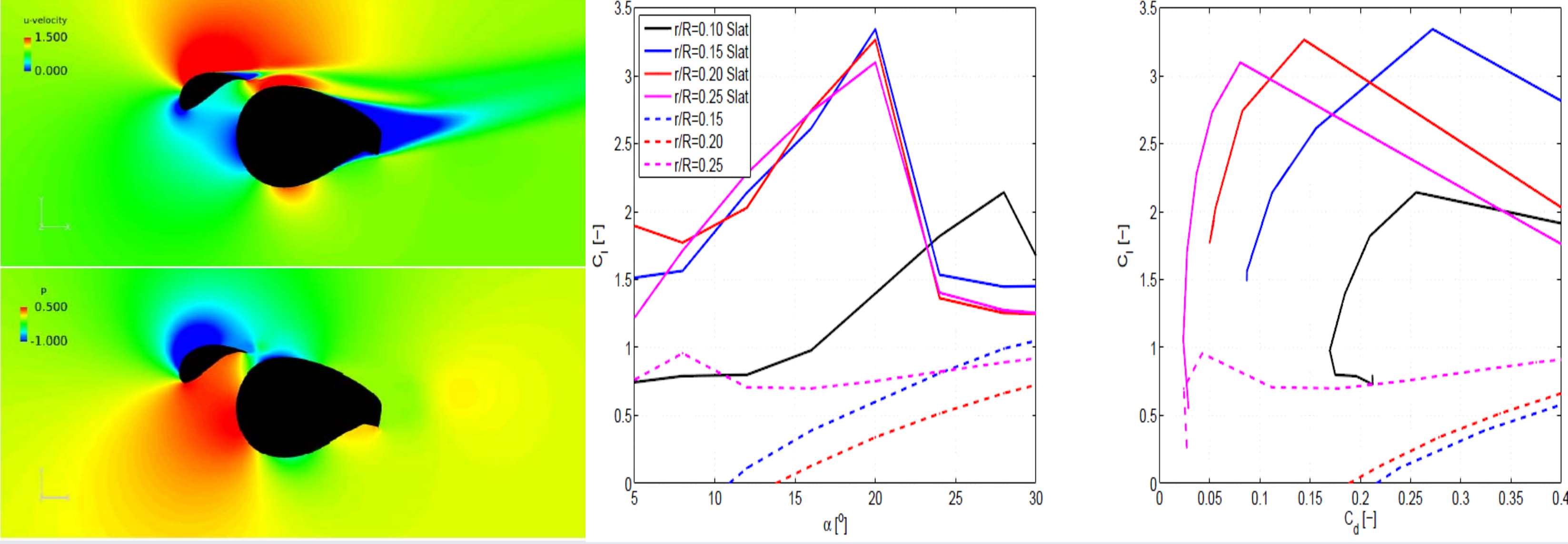


The shapes of the four optimized slatted sections for the inner part of the rotor is shown to the right

The optimization algorithm adjusts the slat parameters to optimize the performance of the combined configuration at the design angle of attack.



The figures below show the flow features at the design point of the 74% thick main airfoil section(left), and the performance of all four slatted sections (right) computed with the EllipSys2D CFD tool.



It is seen that the very thick airfoil sections obtain very high lift coefficients using the slats. The performance of the main airfoils alone are given with the dashed curves

Impact on energy production

The impact on the energy production of design iteration #1 of the RWT10MW rotor is shown in the table below.

The results indicate that slats may indeed be used to boost the aerodynamic performance of the inner part of rotors.

$ V_\infty $	6 m/s	7 m/s	8 m/s	9 m/s
2D pol.	-3.1%	-2.5%	-2.1%	-1.8%
Slat	+1.4%	+1.2%	+1.0%	+0.8%

Table 3: Increase in annual energy production compared to (the stall delay corrected) reference case, BEM results. Weibull wind distributions with shape factor 2.

Conclusions

The article-counterpart of this poster have:

- Described a new CFD based tool for optimization of slats for thick airfoils
- Described a BEM-based simplified theory to aid in the design of slatted rotors
- Found that the power production potential by fitting slats on the inner part of design iteration 1 of the (quite heavily loaded) 10MW reference turbine is likely to be more than 1% AEP
- Stated that the beneficial effects of using slats may be larger if the slats and the main rotor blade are designed simultaneously
- Found that further work is needed to determine the AEP increase more accurately due to uncertainties in rotational effects/stall-delay
- Suggested that 3D CFD should be used to investigate a rotor with slats on to dig into these interesting issues

Acknowledgements

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